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Natural Language Processing Software

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Abstruct

In the Fifth Generation Computer Systems project, the goal of natural language processing (NLP) is to build an intelligent user interface for the proto-type machine of the Fifth Generation.

In the initial and intermediate stage of our project, mathematical and linguistic theories of discourse understanding was investigated and we built some experimental systems for the theories. In the final stage, we have built a system of general tools for NLP and, using them, developed experimental systems for discourse processing, based on the result and experience of the software development in the past two stages.

In the final stage, we have four themes of NLP research and development.

The first theme, *Language Knowledge-base*, is a collection of basic knowledge for NLP including Japanese grammar and Japanese dictionary. In the second theme, *Language Tool Box*, we have developed several basic tools especially for Japanese processing. Tools are: morphological and syntax analyzers, sentence generator, concordance system, and *etc.* These two themes form the infrastructure of our NLP systems.

Experiment with discourse processing is the third and main theme of our research. We have developed several systems in this field including text generation, discourse structure construction, and dialog systems.

The last theme is parallel processing. We have developed an experimental system for cooperative parallel natural language processing in which morphological analysis, syntax analysis, and semantic analysis are integrated in a uniform process in a type inference framework.

1 Introduction

To establish an intelligent interface between machine and human, it is necessary to research discourse processing. In discourse processing we include not only discourse understanding where compter understands the contents of utterances of human and infers the human's intention.

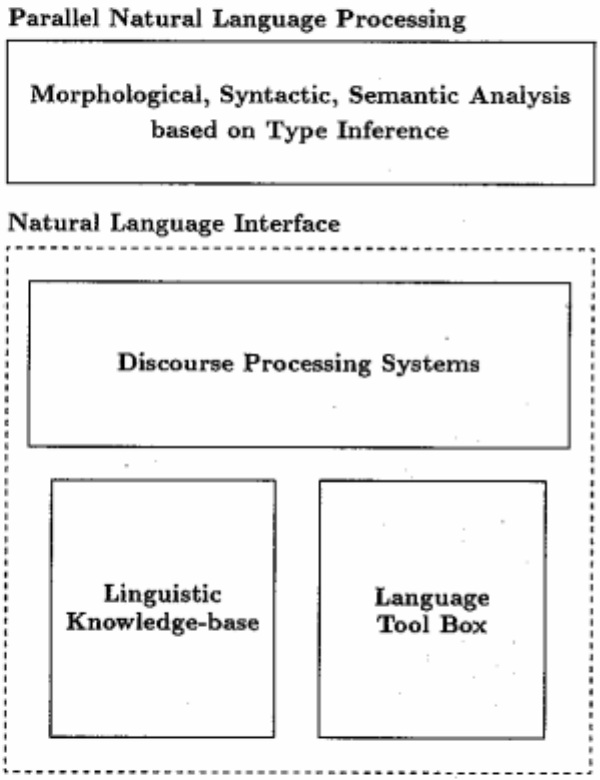

Figure 1: Overview of NLP Software

but also text generation by which more than one sentences expressing speaker's consistent assertion are produced. We put this discourse processing research at the center of our research and development activity, and also develop some supporting tools and data as the infrastructure.

Language Knowledge-base is a collection of basic knowledge for natural language processing including Japanese grammar and Japanese dictionary. We have build a Japanese grammar in phrase structure grammar based on unification grammar formalism. Until now,

there were no Japanese grammar with sufficient size for practical use and usable by every researcher and developer. The purposes of development of this grammar are these two points. It is written in DCG (Definite Clause Grammar) based on the exhaustive investigation of Japanese language phenomena.

Also we have developed a Japanese grammar based on dependency grammar formalism. To reduce ambiguity arisen during analysis, we introduced structural and linguistic constraints on dependency structure based on a new concept 'rank' for each word and word pair.

Adding to the Japanese grammar, we have developed a large-scale Japanese dictionary for morphological analysis. It has about 150,000 entries including more than 40,000 proper nouns so that it can be used for morphological analysis of newspaper articles. These grammar and dictionary are described in section 2.

Language Tool Box is a collection of basic NLP tools especially for Japanese processing. Input and output modules for some experimental NLP systems we made so far, mainly Japanese morphological analyzer, syntax analyzer and sentence generator, were useful for other NLP applications. We have refined their user-interface, made programs robust to unexpected inputs, and increased efficiency to make them easier to apply to various applications.

Currently, not only input and output tools are included in this collection, but also supporting tools for lexicographers and grammar writers such as concordance system and grammar editor. The description of these tools and their publication will be appeared in section 3.

Development of discourse processing systems is the main theme of our research. We have collected rules for language phnomena concerning discourse, and developed several experimental systems in this field including text generation, discourse structure construction, and dialog systems. The text generation system produces one or more paragraphs of text concerning to a given theme based on its belief and judgement. The discourse structure construction system uses discourse rules as a grammar to construct a tree-like discourse structure of a given text. The experimental dialog systems handle user's intention, situation, and position to remove user's misunderstanding and to produce user friendly responces. These system are described in section 4.

As parallel NLP experiment, we have developed a small system for cooperative processing in which morphological analysis, syntax analysis, and semantic analysis are amalgamated into a uniform process in a type inference framework. This system, running on multi-PSI machine, achieves about 12 speed up rate using 32 PEs. Precise description of the system and the experiment will be appeared in section 5.

The overview of the whole activity for these four themes is shown in Figure 1.

2 Linguistic Knowledge-base

Language Knowledge-base is a collection of basic knowledge for natural language processing including Japanese grammar and Japanese dictionary. We have build a Japanese grammar in phrase structure grammar based on unification grammar formalism. There has been no set of standard Japanese grammar rules which people get and handle easily and quickly. This is an obstacle for researchers in Japanese language processing who try to make experimental systems to prove some ideas or who try to build application systems in various field. Our Japanese grammar has been developed to overcome such obstcles and designed as a standard in a sense that it covers most of the general language phenomena and it is written in a common form to various environment. DCG (Definite Clause Grammar). Also we have developed a Japanese grammar based on dependency grammar formalism. Historically, there have been several Japanese dependency grammar because it is recognized easier to build a dependency grammar rules for Japanese because of loose constraints on word order of Japanese language. We introduced structural and linguistic constraints on dependency structure in order to avoid structural ambiguity. These constraints are based on a new concept 'rank' for each word and word pair.

Adding to the Japanese grammar, we have developed a large-scale Japanese dictionary for morphological analysis. It has about 150,000 entries including more than 40,000 proper nouns so that it can be used for morphological analysis of newspaper articles.

The precise description of Language Knowledge-base will be presented in [Sano and Fukumoto 92] submitted to ICOT session of this conference.

2.1 Japanese Grammar

2.1.1 Localized Unification Grammar

Conventional Japanese grammar for computers are not satisfactory to practical application because they lacked formality, uniformity of precision and exhaustiveness [Kuno and Shibatani 89] [Masuoka 89] [Nitta and Masuoka 89].

Having made an exhaustive investigation, we collected language phenomena and rules to explain those phenomena objectively expressed in a DCG style formal description [Pereira 80]. This description is based on the Unification Grammar formalism [Calder 89] [Carlson 89] [Moens 89]. They covers most of the phenomena appearing in contemporary written text [Sano 89] [Sano *et al.* 90] [Sano and Fukumoto 90]. We classified these phenomena according to the complexity of corresponding surface expressions [Sano 91]. Grammar rules are classified also according to their corresponding phnomena. The classification of phenomena (rules) is shown in Table 1.

Table 1: Classification of Grammar Rules

level	phenomena
1~2	single predicate
3~4	negation / aspect / honorification
5	subject+complement+predicate / topicalization
6	passive / causative
7~8	modification (to nouns / to verbs)
9	particles (1) / coordination (2)
10~11	compound sentence / condition
12	particles (2) / coordination (2) / conjunction

The syntactic-semantic structure of sentence is shown in Figure 2. In this figure, State-of-affairs (*SOA*) is the minimum sub-structure of the whole structure. A *SOA* has a predicate with some cases and optional complements. Composition of one or more *SOA*s form a description. The semantic contents of a sentence is a description preceded by a *Topic*. And furthermore the semantics of a sentence contains speaker's intention expressed by *Modal*.

According to this structure, rules of each level (Table1) are divided into several groups. Rules of outermost group analyze speaker's intention through the expression at the end of sentences. Rules of the second group analyze topic-comment structure, that is a dependency relation between a topicalized noun phrase marked by a particle "*wa*" and the main predicate. And rules for analyzing description, voice, *etc.* follow.

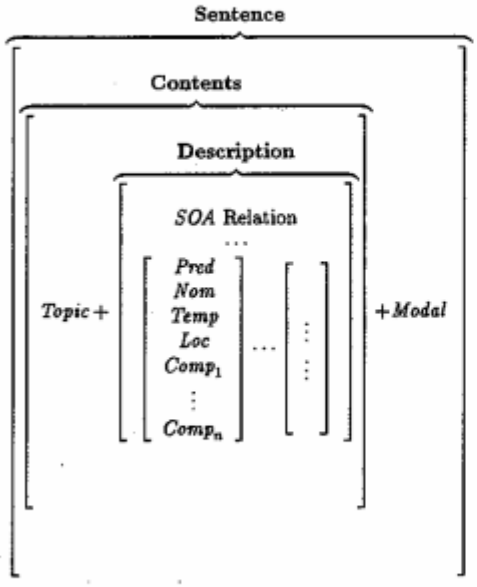

Figure 2: Syntactic-Semantic Structure of a Sentence

An Example of the rules for topic-comment structure will be shown in Figure 3.

$$Cat_0(SYN_2, X_2, \left[topic(X_2, \left\{ \begin{array}{c} SYN_1, \\ REL_1, \\ F_1 \end{array} \right\}) \middle| REL_2 \right], F_2, (X, Z)) \Rightarrow$$
$$Cat_1(SYN_1, X_1, REL_1, F_1, (X, Y)).$$
$$Cat_2(SYN_2, X_2, REL_2, F_2, (Y, Z)).$$

Figure 3: An Example of LUG Grammar Rules

2.1.2 Restricted Dependency Gramar

For Japanese language, there has been many researches on dependency grammar because there are no strong constraints of word order in Japanese [Kodama 87]. In these researches, in order to determine whether a word depends on other, no global information are used but that of only these two words. However, this kind of local information is not sufficient to recognize the structure of whole sentence including topic and ellipsis. Consequently, wrong interpretation of a sentence are produced as a result of dependency analysis [Sugimura and Fukumoto 89].

We introduced structural and linguistic constraints on dependency structure in order to avoid this kind of structural ambiguity. These constraints are described in terms of rank for each word and word pair. Rank represents strength of dependency between words which reflects global information in a whole sentence [Fukumoto and Sano 90]. Definition of ranks and their constraints are described in [Sano and Fukumoto 92] in detail.

Figure 4 shows a structural ambiguity and its resolution. For the sentence "*Kare-ga yobu-to dete-kita.* (When he called ϕ_1, ϕ_2 appeared.)", only the interpretation (a) is adopted because an arc of rank a cannot stretch over that of rank d.

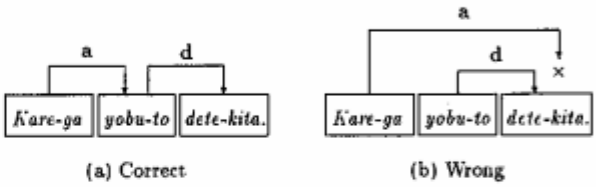

Figure 4: Ambiguity Resolution in RDG Analysis

2.2 Japanese Dictionary

We have developed a concordance system as a tool in *Language Tool Box* (LTB). To serve a huge amount of text data for the concordance system, automatic morphological analysis is necessary. Our large-scale morphological Japanese dictionary has been designed to that purpose.

This Japanese dictionary has about 150.000 entries including more than 40.000 proper nouns so that it can be used for morphological analysis of newspaper articles.

2.3 Software Publication

Japanese grammar and Japanese dictionary stated above will be distributed from ICOT. Japanese grammar in DCG form can be easily installed in any Prolog environment. Japanese dictionary will be distributed with its access method and indexing program which produces TRIE index file for the dictionary entries. Those dictionary programs are written in C.

3 Language Tool Box

Language Tool Box is a collection of basic, general-purpose NLP tools especially for Japanese processing. In the initial and intermediate stage of this project, we developed several experimental systems for discourse understanding so far. As the result of the experiments, the input and output modules for those systems, mainly Japanese morphological analyzer, syntax analyzer and sentence generator, were proved to be useful for other NLP systems. Since then, we have refined their user-interface, made programs robust to unexpected inputs, and increased efficiency to make them easier to apply to various applications.

Currently, not only input and output tools are included in this collection, but also supporting tools for grammar writers and lexicographers such as concordance system with complex key input, browsing / editing / experiment tools for Japanese grammar, and so on.

These software were not applicable for general machines though they were designed general-purpose, because they had been written in ESP, the user language for Personal Sequential Inference Machine PSI. To solve this problem, we transplanted some of these software to CESP (Common ESP) language which was designed as a similar programming language to ESP running on many UNIX workstations.

3.1 Morphological Analysis Tools

Morphological analyzer LAX, located in the front end of LTB, analyzes an unsegmented string of Japanese sentence into a sequence of words and composes semantics of each word from those of morphemes [Kubo *et al.* 88] [Kubo 89] [Sugimura *et al.* 88] [Okumura and Matsumoto 87a] [Okumura and Matsumoto 87b]. It makes use of connectivity matrix which originated from kana-kanji conversion [Aizawa and Ehara 73]. The morpheme dictionary has a TRIE index [Nakajima and Sugimura 89] to improve search speed.

Since there will be, generally, more than one solution for a input sentence in morphological analysis, the most plausible solution is selected by the words minimizing method [Yoshimura *et al.* 82]. The morphology grammar used in this system follows [Morioka 87] and [Sano *et al.* 88].

This system can be also used for developing and extending morphology grammar and dictionary. User interface for that purpose has been deeply considered [Shiraishi *et al.* 90] [Yoneda *et al.* 89].

Configuration of the LAX system is shown in Figure 5 in detail. Total system of this figure is implemented on PSI machine in ESP (Extended Self-contained Prolog). We are now transplanting the system part by part in CESP (Common ESP) to UNIX workstations.

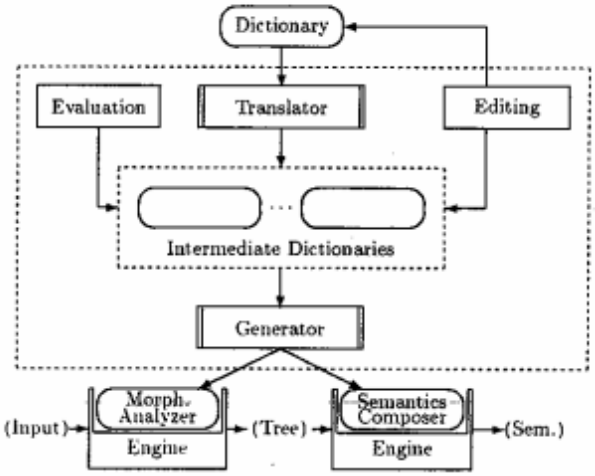

Figure 5: System Configuration of LAX

3.2 Syntax Analysis Tools

Basic algorithm of the syntax analyzer SAX, called AX (Analyzer for syntaX), was first developed in a parallel logic programming language Parlog as a parallel analyzer, then transplanted in GHC [Ueda and Chikayama 90] into parallel analyzer PAX, and in Prolog and ESP into sequencial analyzer SAX [Matsumoto and Sugimura 87] [Okumura and Matsumoto 87a].

The PAX system has been rewritten in KL1 and serves a practical syntax analyzer on Multi-PSI machines [Okumura and Matsumoto 87b] [Satoh 90]. On the other hand, SAX system runs on PSI machine (ESP version) and UNIX workstations (Sicstus-Prolog version; developed at Kyoto University).

3.3 Grammar Writer's Workbench

We have developed a tool for grammar writers. The tool, named LINGUIST, has a simple all-in-one structure described in Fingure 6.

The purpose of this system is to help a grammar writer in evaluation, tracing, and correction of his grammar very easily.

The system has three tools: Generator, Accessor and Debugger. The Generator is a BUP translator [Mat-

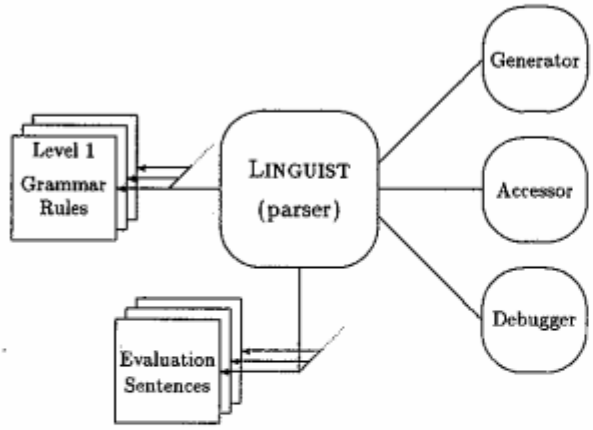

Figure 6: Configuration of LINGUIST System

sumoto *et al.* 83a] [Matsumoto *et al.* 83b] itself which reads a set of grammar rules written in DCG (Definite Clause Grammar) [Pereira 80] and generates a syntax parser. The resulting parser is a core of the system.

The Accessor is a tool for managing linguistic data such as sentences for evaluation, result of analysis (internal representation). One can inspect analysis result with complicatedly nested structure (see section 2.1.1) as a frame or as a graph using structural inspector of the Accessor.

The Debugger contains screen tracer and source level debugger, the former of which displays (partial) syntax tree dynamically with a grammar rule used at that point, and the latter provides correcting function to the source grammar rules at run time.

The LINGUIST system is also transplanted in CESP and, in this case, total system runs on UNIX machines.

3.4 Concordance Tool

When one begin to build a grammar or a dictionary, it is indispensable to collect actual linguistic data from living materials like literature, newspaper and documents.

Concordance or KWIC (Keyword in Context) system is designed for this purpose. It stores large amount of text data and provides searching function on it. When a word or a combination of words is put to the system, it searches text database to retrieve sentences that contain input word(s).

In our concordance system, not only word but also variety of keyword specification are available as input. One can specify compound keyword as

$$k_1\ f_1\ k_2 \cdots f_{n-1}\ k_n$$

where k_i denotes i-th keyword and f_i filler. Fillers, being either definite length (0 or more) or wild card, specify number of words to be discarded between keywords. Keyword can be one of the following or combination of them:

- Surface form (kanji, inflected)
- Root form (kanji, uninflected)
- Reading (kana)
- Part of speech
  - Inflection type
  - Inflected form

One can thus specify a keyword like

{ POS/ verb,
Inflected_form/ *rentai-kei* }.

This system was implemented in ESP on PSI machine at first, then transplanted to CESP.

3.5 Other Tools

There are some more tools in LTB.

CIL is a variation of Prolog. It has frame-like data types (PST: Partially Specified Term) and freeze control structure. In the program segment

```
print(X?),
...
{name/ tanaka, age/ 25} = {age/ X},
...
```

when two PST's are unified, variable X is instantiated, then the freezed term print(X?) is melted to print 25.

The sentence division tool is a one to divide long sentences into the combination of shorter ones to reduce structural ambiguity. It is applied on LAX output.

The sentence generation tool [Ikeda *et al.* 88] generates a Japanese sentence from a internal representation of PST form:

```
{relation/
   {word/ tayo-ru}
 role/
   {goal/
      {comp/
         {modificand/
            {word/ megumi},
   ...
 modal/
   {mood/ [inevitable]}}.
```

CIL is written in ESP, while other two tools were transplanted to CESP.

3.6 Software Publication

Software tools introduced above will be distributed in source codes from ICOT. Programs written in CESP can be executed on several UNIX workstations. Access AIR (AI Language Research Institute, Ltd.) for detail information of CESP language and how to obtain it.

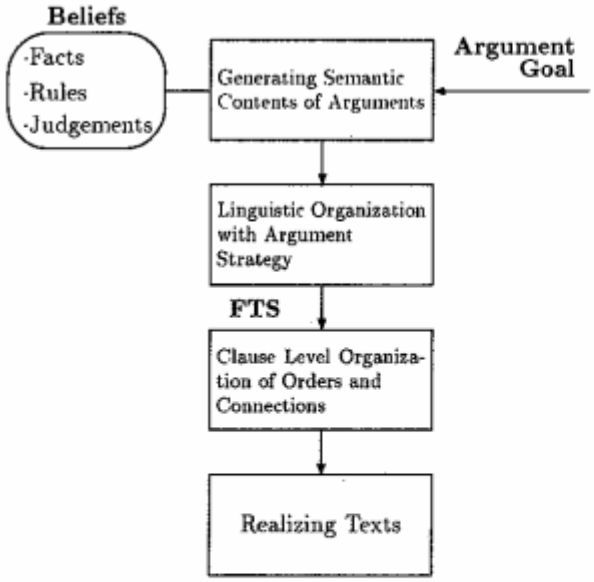

Figure 7: Configuration of the Argument Text Generation System

4 Discourse Processing Systems

In the experiments of discourse processing systems, we have collected rules for language phnomena concerning discourse, and developed several experimental systems in this field including text generation, discourse structure construction, and dialog systems.

The text generation system has a system's belief as a knowledge-base, and produces one or more paragraphs of text concerning to a given theme based on its belief and judgement using rhetorical heuristics.

The discourse structure construction system uses rules for classification of sentence types and of relationship between sentences in a discourse to construct a tree-like discourse structure of a given text.

4.1 Argument Text Generation

As described in the previous section, we have developed sentence generation tool as one of the LTB tools. This program generates single sentence from an internal representation which specifies many semantic and surface attributes of the sentence precisely [Ikeda *et al.* 88]. As a tool, it is not so convenient because the user must be aware of internal representation and grammatical rules.

Moreover, main topic of sentence generation has shifted to paragraph or full text generation. And the quality of generated sentences has raised higher so that speaker's intention and position can be expressed [Tokunaga and Inui 91]. In order to realize such functions in generation, planning text structure, semantic contents, hearer's intention is important [Appelt 88] [Hovy 85] [Hovy 90a].

Against this background, we developed a generation system for argument text. This system generates a text by which the system tries to pursuade the hearer in a given argument. The configuration of the system is shown in Figure 7. Detailed description of this system is given in the paper [Ikeda *et al.* 92] in ICOT session of this conference.

The system has his belief as a knowledge-base. It contains facts, rules and his judgement about world events. If this judgement is substituted by another, remaining facts and rules left unchanged, then the system draw a different conclusion for the same object.

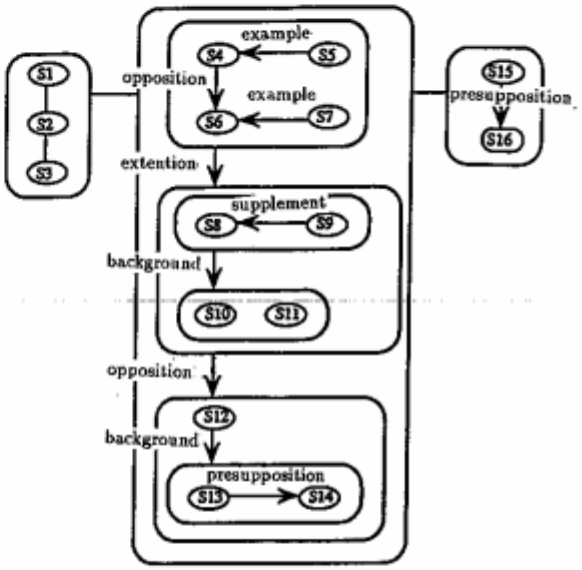

Figure 8: An Example of a Text Structure

4.2 Discourse Structure Extraction

First step of discourse structure extraction is to classify sentences in a context into several sentence types, such as assertive, descriptive, interrogative, and *etc.* Then, using these sentence types and relation between adjacent sentences, sentences will be gathered together into sentence groups. At the same time, relation between groups will be analyzed. Intergroup relationship contains: example, extention, supplement, opposition, background, presupposition, and *etc.* [Ichikawa 78] [Kinoshita *et al.* 89] These groups can be regarded as paragraphs and paragraph segments [Fukumoto 90] [Shibata *et al.* 90] [Fukumoto and Yasuhara 91] [Saitoh *et al.* 91] [Tanaka *et al.* 91] [Sakuma 88] [Tsujii 89] [Yamanashi 89].

Rules for classifying sentence types and those of analyzing intergroup relationship are described in a formal language, and will be published as a "context grammar."

Figure 8 is an example of a text structure of an editorial of Japanese newspaper with 16 sentences.

The experimental system on the Multi-PSI machine will be demonstrated in this conference.

5 Parallel NLP Experiment

As parallel NLP experiment, we have developed a small system for cooperative processing in which morphological analysis, syntax analysis, and semantic analysis are amalgamated into a uniform process in a type inference framework.

Most of the conventional NLP systems have been designed a collection of independently acting modules. Processing in each module is hidden from the outer world, and we use these modules as black-boxes. But since parallel cooperative processing needs internal information being exchanged between modules, we must adopt other framework for parallel NLP.

One answer to this problem is to abstract processing mechanism to merge all such processing as morphology, syntax, semantics, and *etc.* Constraint transformation proposed by Hasida [Hashida 91] is one of the candidates of this framework. We proposed a type inference method [Martin-Löf 84] as another candidates. This type inference mechanism is based on a typed record structure [Sells 85] or a record structure of types similar to ψ-term [Aït-Kaci and Nasr 86], sorted feature structure [Smolka 88], *QUIXOTE* [Yasukawa and Yokota 90], order-sorted logic [Schmidt-Schauss 89].

Morphological analysis and syntax analysis is performed by layered stream method [Matsumoto 86]. Roles of process and communication are exchanged in comparison with the method used in PAX [Satoh 90].

This system, running on multi-PSI machine, using a Japanese dictionary with 10,000 nouns, 1000 verbs, 700 concepts, and a Japanese grammar LUG [Sano 91] [Sano and Fukumoto 92], achieves about 12 speed-up rate using 32 processing elements.

Figure 9 shows the relation between number of processors ($1 \sim 32$) and processing time in milli second for a 25-word long sentence.

Figure 10 shows the relation between reductions and speed-up ratio for various evaluation sentences.

The detail of this system will be presented in the paper [Yamasaki 92] submitted to this conference.

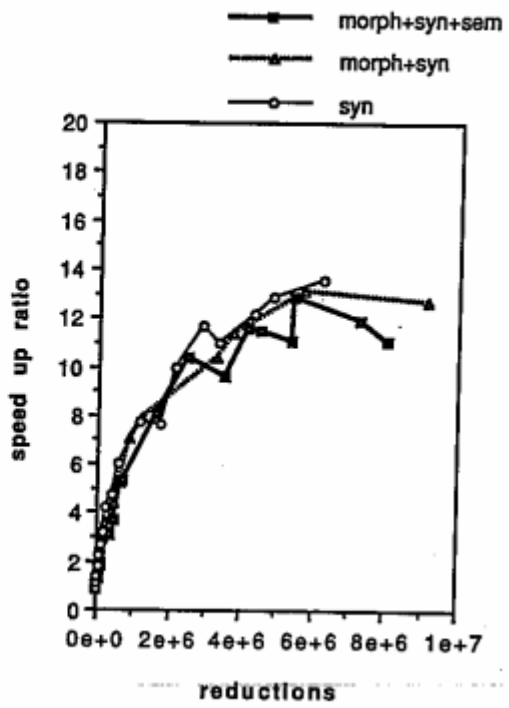

Figure 9: Performance of Experimental System (1)

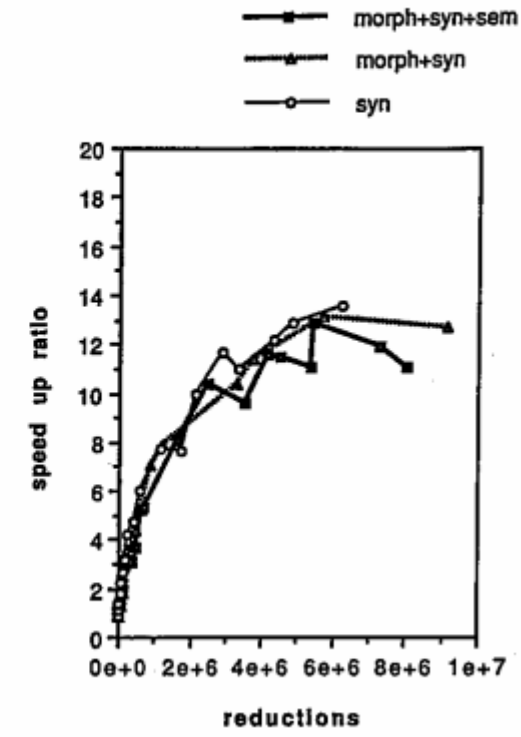

Figure 10: Performance of Experimental System (2)

Acknowledgment

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References

[Abe *et al.* 91] H. Abe, T. Okunishi, H. Miyoshi, and Y. Obuchi. A Sentence Division Method using Connectives. In *Proc. of the 42nd Conference of Information Processing Society of Japan* (in *Japanese*). 1991. pp. 13-15.

[Aït-Kaci and Nasr 86] H. Aït-Kaci and R. Nasr. LOGIN: A Logic Programming Language with Built-in Inheritance, *The Journal of Logic Programming*, Vol. 3, No. 3, Oct. 1986.

[Aizawa and Ehara 73] T. Aizawa and T. Ehara. Kana-Kanji Conversion by Computer (in *Japanese*), *NHK Technical Research*, Vol. 25, No. 5, 1973.

[Appelt 85a] D. E. Appelt. *Planning English Sentences*. Cambridge University Press, 1985.

[Appelt 85b] D. E. Appelt. Bidirectional Grammar and the Design of Natural Language Generation Systems, In *Proc. TINLAP-85*, 1985.

[Appelt 87] D. E. Appelt. A Computational Model of Referring, In *Proc. IJCAI-87*, 1987.

[Appelt 88] D. E. Appelt. Planning Natural Language Referring Expressions. In David D. McDonald and Leonard Bolc (eds.), *Natural Language Generation Systems*. Springer-Verlag, 1988.

[Barwise and Perry 83] J. Barwise and J. Perry. *Situation and Attitudes*, MIT Press, 1983.

[Brooks 86] R. A. Brooks. A Robust Layered Control System for a Mobile Robot. *IEEE Journal of Robotics and Automation*, Vol. Ra-2, No. 1. March, 1986.

[Calder 89] Jonathan Calder, Ewan Klein, Henk Zeevat. Unification Categorial Grammar. In *Proc. of the Fourth Conference of the European Chapter of the ACL*, Manchester, 1989.

[Carlson 89] Lauri Carlson. RUG: Regular Unification Grammar. In *Proc. of the Fourth Conference of the European Chapter of the ACL*, Manchester, 1989.

[Danlos 84] L. Danlos. Conceptual and Linguistic Decisions in Generation. In *Proc. of the International Conference on Computational Linguistics*, 1984.

[De Smedt 90] K. J. M. J. De Smedt. Incremental Sentence Generation. *NICI Technical Report*, 90-01, 1990.

[Fujisaki 89] H. Fujisaki. Analysis of Intonation and its Modelling in Japanese Language. *Japanese Language and Education of Japanese* (in *Japanese*). Meiji Shoin Publishing Co., 1989, pp. 266-297.

[Fukumoto and Sano 90] F. Fukumoto, H. Sano. Restricted Dependency Grammar and its Representation. In *Proc. The 41st Conference of Information Processing Society of Japan* (in *Japanese*), 1990.

[Fukumoto 90] J. Fukumoto. Context Structure Extraction of Japanese Text based on Writer's Assertion. In *Research Report of SIG-NL*, Information Processing Society of Japan (in *Japanese*). 78-15, 1990.

[Fukumoto and Yasuhara 91] J. Fukumoto and H. Yasuhara. Structural Analysis of Japanese Text. In *Research Report of SIG-NL*, Information Processing Society of Japan (in *Japanese*). 85-11, 1991.

[Grosz and Sidner 85] B. Grosz and C. L. Sidner, The structures of Discource Structure, Technical Report CSLI, CSLI-85-39, 1985.

[Hashida 91] K. Hasida. Aspects of Integration in Natural Language Processing, *Computer Software*. Japan Society for Software Science and Technology, Vol. 8, No. 6. Nov. 1991.

[Hovy 85] E. H. Hovy. Integrating Text Planning and Production in Generation. In *the Proceedings of the International Joint Conference on Artificial Intelligence*. 1985.

[Hovy 87] E. H. Hovy. Interpretation in Generation. In *the Proceedings of 6th AAAI Conference*. 1987.

[Hovy 88] E. H. Hovy. *Generating Natural Language under Pragmatic Constraints*. Lawrence Erlbaum Associates. Publishers, 1988.

[Hovy 90a] E. H. Hovy. Unresolved Issues in Paragraph Planning. In *Current Research in Natural Language Generation*. Academic Press. 1990.

[Hovy 90b] E. H. Hovy. Pragmatics and Natural Language Generation. *Artificial Intelligence 43*, 1990. pp. 153–197.

[Ichikawa 78] T. Ichikawa. *An Introduction to Japanese Syntax for Teachers*. Kyoiku Shuppan Publishing Co., 1978.

[Ikeda *et al.* 88] T. Ikeda, K. Hatano, H. Fukushima and S. Shigenaga. Generation Method in the Sentence Generator of Language Tool Box (LTB). In *Proc. of the 5th Conference of Japan Society for Software Science and Technology* (in *Japanese*), 1988.

[Ikeda 91] T. Ikeda. Natural Language Generation System based on the Hierarchy of Semantic Representation (in *Japanese*). *Computer Software*, Japan Society for Software Science and Technology, Vol. 8, No. 6, Nov. 1991.

[Ikeda *et al.* 92] T. Ikeda, A. Kotani, K. Hagiwara, Y. Kubo. Argument Text Generation System (Dulcinea). In *Proc. of FGCS '92*, ICOT, Jun. 1992.

[Katoh and Fukuchi 89] Y. Katoh and T. Fukuchi. *Tense, Aspect and Mood* (in *Japanese*). Japanese Example Sentences and Problems for Foreigners 15. Aratake Publishing Co., Tokyo. 1989.

[Kempen and Hoenkamp 87] G. Kempen and E. Hoenkamp. *An Incremental Procedural Grammar for Sentence Formulation*, Cognitive Science, Vol. 11. 1987.

[Kinoshita 81] S. Kinoshita. Writing Techniques in Scientific Field (in *Japanese*). Chuo-Kouron Publishing Co., 1981. pp. 82-88.

[Kinoshita *et al.* 89] S. Kinoshita, K. Ono, T. Ukita and M. Amano. Discourse Structure Extraction in Japanese Text Understanding. In *Symposium on Discourse Understanding Model and its Application* (in *Japanese*), Information Processing Society of Japan, 1989. pp. 125-136.

[Kodama 87] T. Kodama. Research on Dependency Grammar (in *Japanese*). Kenkyu-sha, 1987. pp. 161-194.

[Kubo *et al.* 88] Y. Kubo, M. Yoshizumi, H. Sano. K. Akasaka and R. Sugimura. Development Environment of the Morphological Analyzer LAX. In *Proc. of the 37th Conference of Information Processing Society of Japan* (in *Japanese*). 1988. pp. 1078-1079.

[Kubo 89] Y. Kubo. Composition of Word Semantics in Morphological Analyzer LAX. In *Proc. of the 39th Conference of Information Processing Society of Japan* (in *Japanese*). 1989. pp. 598-599.

[Kuno and Shibatani 89] S. Kuno, K. Shibatani. New Development in Japanese Linguistics (in *Japanese*). Kuroshio Publishing Co., Tokyo, 1989.

[Littman and Allen 87] D. J. Littman and J. F. Allen. A Plan Recognition Model for Subdialogues in Conversation, *Cognitive Science* 11, 1987. pp. 163-200.

[Mann and Thompson 86] W. C. Mann and S. A. Thompson. Rhetorical Structure Theory: Description and Construction of Text Structure. In *Proc. of the Third International Workshop on Text Generation*, 1986. In Dordrecht (ed.). *Natural Language Generation: New Results in Artificial Intelligence, Psychology, and Linguistics*. Martinus Nijhoff Publishers, 1987.

[Martin-Löf 84] P. Martin-Löf. Intuitionistic Type Theory — Studies in Proof Thoery, *Lecture Notes*, 1984.

[Masuoka 89] T. Masuoka, Y. Takubo. Basic Japanese Grammar (in *Japanese*). Kuroshio Publishing Co., Tokyo. 1989.

[Matsumoto *et al.* 83a] Y. Matsumoto, M. Seino. H. Tanaka. BUP Translator (in *Japanese*). Bulletin of the Electrotechnical Laboratory, Vol. 47, No. 8. 1983.

[Matsumoto *et al.* 83b] Yuji Matsumoto, H. Tanaka, H. Hirakawa, H. Miyoshi and H. Yasukawa, BUP: A Bottom-up Parser Embedded in Prolog, *New Generation Computing*, Vol. 1, 1983.

[Matsumoto 86] Y. Matsumoto. A Parallel Parsing System for Natural Language Analysis, *Proc. of 3rd Internatioanl Conference on Logic Programming*, London, 1986. *Lecture Notes in Computer Science* 225. pp. 396-409, 1986.

[Matsumoto and Sugimura 87] Y. Matsumoto and R. Sugimura. A Parsing System based on Logic Programming. In *Proceedings of the International Joint Conference of Artificial Intelligence*, 1987.

[Matsumoto 90] Y. Matsumoto and A. Okumura. Programming Searching Problems in Parallel Logic Programming Languages — An Extention of Layered Streams —. In *Proc. of the KL1 Programming Workshop '90* (in *Japanese*). 1990.

[Maruyama and Suzuki 91] T. Maruyama and H. Suzuki. Cooperative Sentence Generation in Japanese Dialog based on Simple Principles (in *Japanese*). In *Proc. of the 8th Conference of Nihon Ninchi Kagaku Kai* (in *Japanese*). 1991.

[McKeown 85a] K. R. McKeown. *Text Generation: Using Discourse Strategies and Focus Constraints to Generate Natural Language Text*. Cambridge University Press. 1985.

[McKeown 85b] K. R. McKeown. Discourse Strategies for Generating Natural-Language Text, *Artificial Intelligence 27*, 1985. pp. 1-41.

[Meteer 90] M. W. Meteer. The 'Generation Gap' — the Problem of Expressibility in Text Planning. *Technical Report*. BBN Systems and Technologies Corporation. 1990.

[Minami 74] F. Minami. The Structure of Contemporary Japanese Language (in *Japanese*). Taishu-kan Publishing Co.. 1974.

[Moens 89] Marc Moens. Jonathan Calder. Ewan Klein. Mike Reape. Henk Zeevat. Expressing Generalizations in Unification-based Grammar Formalisms. In *Proc. of the Fourth Conference of the European Chapter of the ACL*, Manchester, 1989.

[Morioka 87] K. Morioka. *Vocabulary Construction* (in *Japanese*). Meiji Shoin Publishing Co., 1987.

[Morita 89] Y. Morita. *Dictionary of Basic Japanese* (in *Japanese*). Kadokawa Publishing Co., 1989.

[Morita and Matsuki 89] Y. Morita and Y. Matsuki. *Sentence Types of Japanese* (in *Japanese*). ALK Publishing Co., Tokyo. 1989.

[Nagano 86] K. Nagano. *Japanese Syntax — a Grammatical Study* (in *Japanese*). Asakura Publishing Co., 1986.

[Nakajima and Sugimura 89] A. Nakajima and R. Sugimura. Japanese Morphological Analysis with TRIE Dictionary and Graph Stack. In *Proc. of the 39th Conference of Information Processing Society of Japan* (in *Japanese*). 1989. pp. 589-590.

[Nitta and Masuoka 89] Y. Nitta and T. Masuoka (eds.), *Modality in Japanese* (in *Japanese*). Kuroshio Publishing Co., Tokyo. 1989.

[NLRI 81] National Language Research Institute. *Demonstratives in Japanese* (in *Japanese*). Ministry of Finance. 1981.

[NLRI 82] National Language Research Institute. *Particles and Auxiliary Verbs of Japanese* (in *Japanese*). Shuei Publishing Co., Tokyo. 1982.

[NLRI 85] National Language Research Institute. *Aspect and Tense of Contemporary Japanese* (in *Japanese*). Shuei Publishing Co., Tokyo. 1985.

[NLRI 89] National Language Research Institute. *Research and Education of Discourse* (in *Japanese*). Ministry of Finance. 1989.

[Nobukuni 89] Y. Nobukuni. Division Algorithm of Long Sentence, In *Proc. of the 39th Conference of Information Processing Society of Japan* (in *Japanese*). 1989. p. 593.

[Okumura and Matsumoto 87a] A. Okumura and Y. Matsumoto. Parallel Programming with Layered Streams. In *Proc. of the 1987 International Symposium on Logic Programming*. San Francisco, September 1987. pp. 224-232.

[Okumura and Matsumoto 87b] A. Okumura and Y. Matsumoto. Parallel Programming with Layered Streams. In *Proc. of the Logic Programming Conference '87* (in *Japanese*), 1987. pp. 223-232.

[Pereira 80] Fernando C. N. Pereira, David H. D. Warren. Definite Clause Grammars for Language Analysis — A Survey of the Formalism and a Comparison with Augmented Transition Networks, *Artificial Intelligence*. Vol. 13, No. 3. 1980. pp. 231-278.

[Saitoh *et al.* 91] Y. Saitoh, M. Shibata and J. Fukumoto. Analysis of Relationship of Adjoining Sentences for Context Structure Extraction. In *Proc. of the 43rd Conference of Information Processing Society of Japan* (in *Japanese*). 1991.

[Sakuma 88] M. Sakuma. Context and Paragraph. *Japanese Linguistics* (in *Japanese*). Vol. 7, No. 2. 1988. pp. 27-40.

[Sano *et al.* 88] H. Sano, K. Akasaka, Y. Kubo and R. Sugimura. Morphological Analysis based on Word Formation. In *Proc. of the 36th Conference of Information Processing Society of Japan* (in *Japanese*), 1988.

[Sano 89] H. Sano. Hierarchical Analysis of Predicate using Contextual Information. In *Symposium on Discourse Understanding Model and its Application* (in *Japanese*), Information Processing Society of Japan, 1989.

[Sano *et al.* 90] H. Sano, F. Fukumoto, Y. Tanaka. Explanatory Description based Grammar — SFTB (in *Japanese*), ICOT-Technical Memo, TM-0885, 1990.

[Sano and Fukumoto 90] H. Sano, F. Fukumoto. Localized Unification Grammar and its Representation. In *Proc. of the 41st Conference of Information Processing Society of Japan* (in *Japanese*), 1990.

[Sano 91] H. Sano. User's Guide to SFTB (in *Japanese*), ICOT, Sep. 1991.

[Sano and Fukumoto 92] H. Sano, F. Fukumoto. On a Grammar Formalism, Knowledge Bases and Tools for Natural Language Processing in Logic Programming. In *Proc. of FGCS '92*, ICOT, Jun. 1992.

[Satoh 90] H. Satoh. Improvement of Parallel Syntax Analyzer PAX. In *Proc. of KL1 Programming Workshop '90* (in *Japanese*), ICOT, Tokyo, 1990.

[Schmidt-Schauss 89] M. Schmidt-Schauß. Computational Aspects of an Order-Sorted Logic with Term Declarations, *Lecture Notes in Artificial Intelligence*, Springer-Verlag, 1989.

[Searl 69] J. R. Searl. *An Essay in the Philosophy of Language*, Cambridge University Press, 1969.

[Sells 85] P. Sells. Lectures on Contemporary Syntactic Theories, *CSLI Lecture Notes*, No. 3, 1985.

[Shibata *et al.* 90] M. Shibata, Y. Tanaka and J. Fukumoto. Anaphora Phenomena in Newspaper Editorials. In *Proc. of the 40th Conference of Information Processing Society of Japan* (in *Japanese*), 1990.

[Shinnou and Suzuki 91] H. Shinnou and H. Suzuki. Utilization of Sound Information in Incremental Analysis. In *Research Report of SIG-NL*, Information Processing Society of Japan (in *Japanese*). 85-7. 1991.

[Shiraishi *et al.* 90] T. Shiraishi. Y. Kubo and M. Yoshizumi. Format of Morpheme Dictionary and Dictionary Improvement. In *Proc. of the 41st Conference of Information Processing Society of Japan* (in *Japanese*), 1990. pp. 193-194.

[Smolka 88] G. Smolka. A Feature Logic with Subsorts, IBM Deutschland, Stuttgart, Germany, *LILOG Report*, No. 33, May 1988.

[Sugimura *et al.* 88] R. Sugimura, K. Akasaka, Y. Kubo, Y. Matsumoto and H. Sano. LAX — Morphological Analyzer in Logic Programming. In *Proc. of the Logic Programming Conference '88* (in *Japanese*), 1988. pp. 213-222.

[Sugimura and Fukumoto 89] R. Sugimura, F. Fukumoto. Dependency Analysis by Logic Grammar. In *Symposium on Discourse Understanding Model and its Application* (in *Japanese*). Information Processing Society of Japan, 1989.

[Suzuki and Tsuchiya 90] H. Suzuki and S. Tsuchiya. Incremental Interpretation of Japanese Utterance. In *Proc. of the 7th Conference of Nihon Ninchi Kagaku Kai* (in *Japanese*). 1990. pp. 46-47.

[Tanaka *et al.* 91] Y. Tanaka, M. Shibata and J. Fukumoto. Repetitive Occurrence Analysis of a Word in Context Structure Analysis System. In *Proc. of the 43rd Conference of Information Processing Society of Japan* (in *Japanese*), 1991.

[Teramura *et al.* 87] H. Teramura, Y. Suzuki, N. Noda and M. Yazawa. *Case Study in Japanese Grammar* (in *Japanese*). Outousha Publishing Co., Tokyo. 1987.

[Tokunaga and Inui 91] T. Tokunaga and K. Inui. Survey of Natural Language Sentence Generation in 1980's. In *Journal of Japanese Society for Artificial Intelligence* (in *Japanese*). Vol. 6. Nos. 3–5. 1991.

[Tomita 87] M. Tomita. An Efficient Augmented Context Free Parsing Algorithm. *Computational Linguistics* 13, 1-2, 31-46, 1987.

[Tsujii 89] J. Tsujii. Context Processing. In *Symposium on Natural Language Processing* (in *Japanese*). Information Processing Society of Japan. 1988. pp. 75-87.

[Ueda and Chikayama 90] K. Ueda and T. Chikayama. Design of the Kernel Language for the Parallel Inference Machine. *The Computer Journal*. Vol. 33. No. 6. Dec. 1990. pp. 494-500.

[Yamanashi 86] M. Yamanashi. *Speech Act* (in *Japanese*). Taishukan Publishting Co., 1986.

[Yamanashi 89] M. Yamanashi. Discourse. Context and Inference. In *Symposium on Discourse Understanding Model and its Application* (in *Japanese*). Information Processing Society of Japan. 1989. pp. 1-12.

[Yamasaki 92] S. Yamasaki. A Parallel Cooperative Natural Language Processing System — Laputa. In *Proc. of FGCS '92*. ICOT. Jun. 1992.

[Yasukawa and Yokota 90] H. Yasukawa and K. Yokota. The Overview of a Knowledge Representation Language *QUIXOTE*. ICOT (draft), Oct. 21. 1990.

[Yoneda *et al.* 89] J. Yoneda, Y. Kubo, T. Shiraishi and M. Yoshizumi. Interpreter and Debugging Environment of LAX. In *Proc. of the 39th Conference of Information Processing Society of Japan* (in *Japanese*). 1989. pp. 596-597.

[Yoshida and Hidaka 87] M. Yoshida and S. Hidaka. *Studies on Documentation in Standard Japanese* (in *Japanese*). 1987.

[Yoshimura *et al.* 82] K. Yoshimura, T. Hidaka and M. Yoshida. On Longest Maching Method and Word Minimizing Method in Japanese Morphological Analysis. In *Research Report of SIG-NL*. Information Processing Society of Japan (in *Japanese*). 30-7. 1982.